

# Turbine Tip Flow Optimization for Modern Aero-Engines

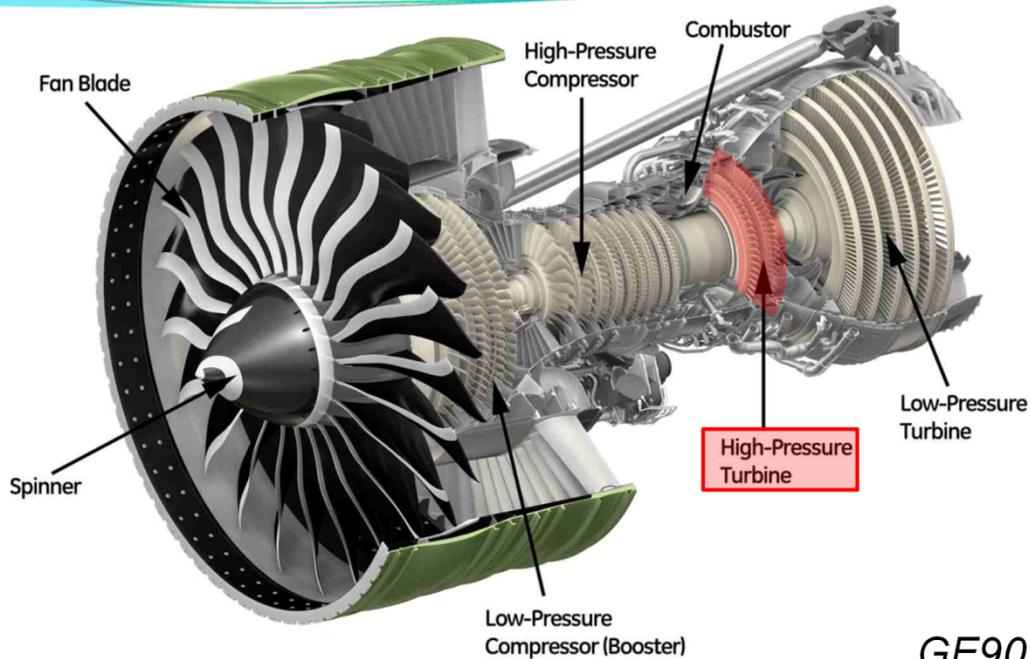
C. De Maesschalck

PhD Candidate

*Turbomachinery and Propulsion Department*

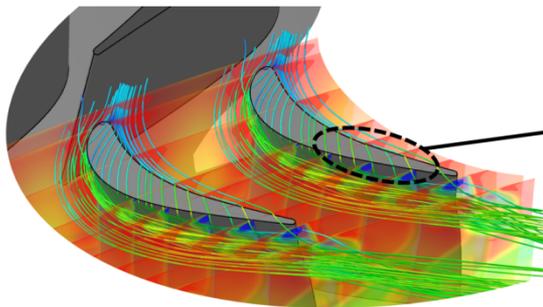
Prof. G. Paniagua (VKI, Purdue University) - Prof. C. Lacor (Vrije Universiteit Brussel)

Dr. S. Lavagnoli



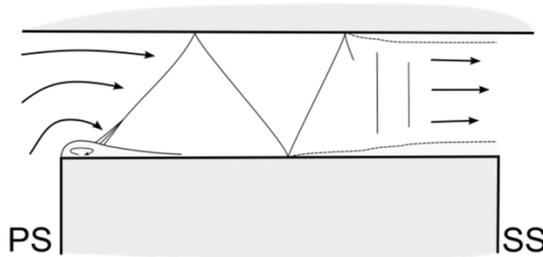
GE90

**Efficiency** ↑



1/3 turbine losses due to tip leakage

**Weight** ↓



Blade loading ↑  
Supersonic tip gap flows

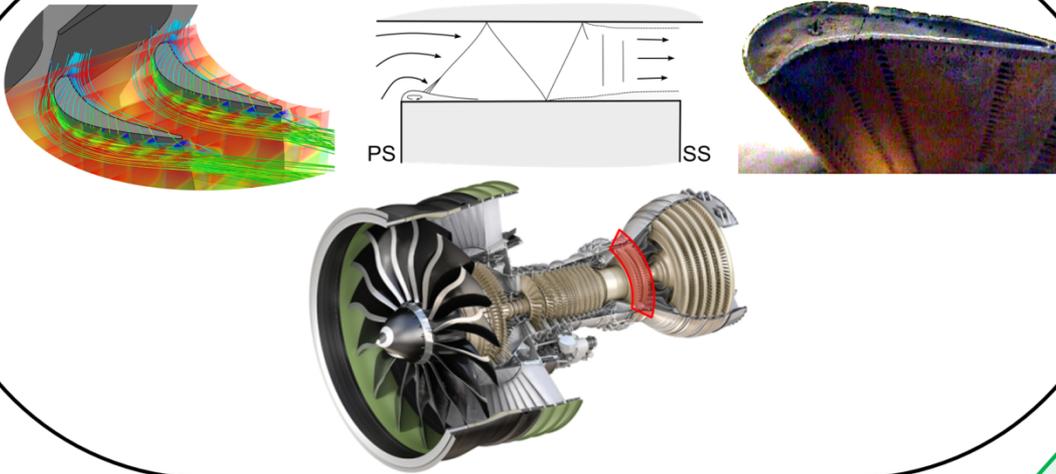
**Durability** ↑



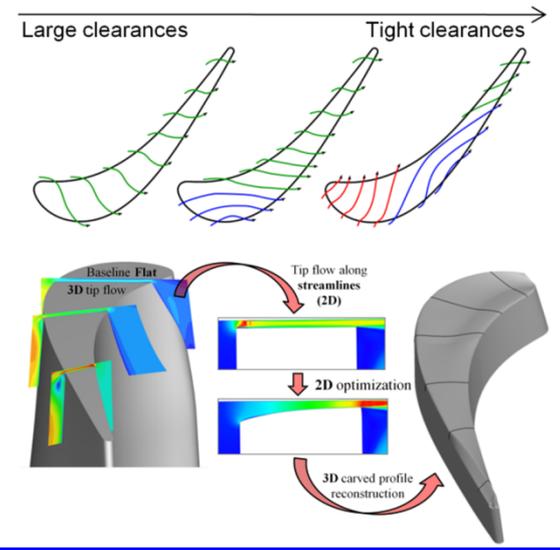
Cooling strategies for heat load control

**Manufacturability & Cost**

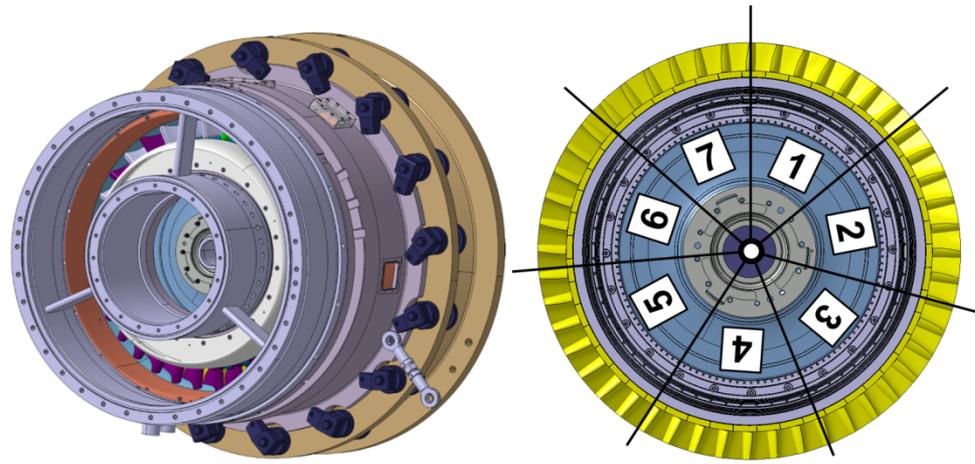
# TURBINE TIP OPTIMIZATION



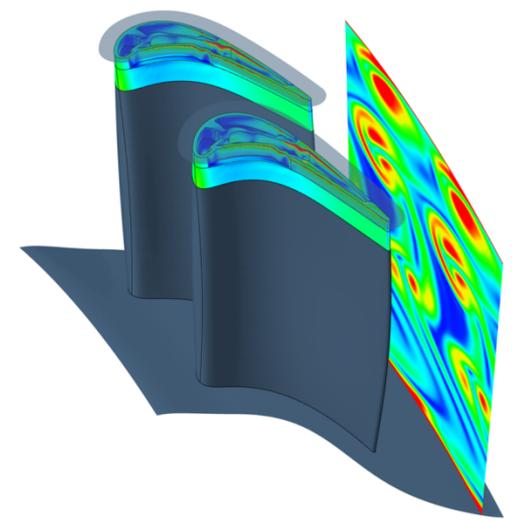
## Exploratory Study



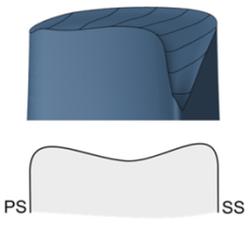
## Experimental Campaign



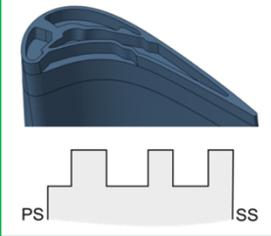
## Numerical Optimization



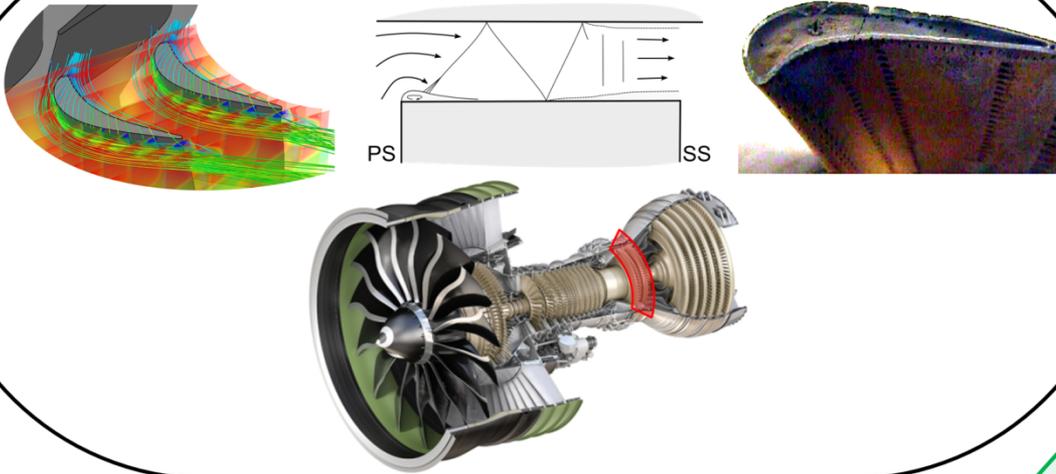
### 1. Contoured designs



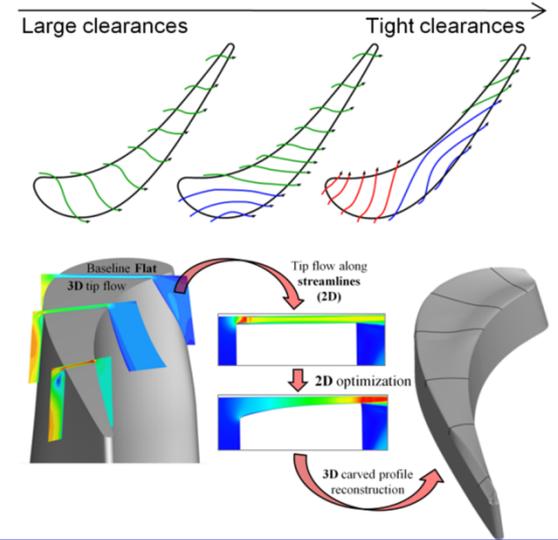
### 2. 'Squealer' designs



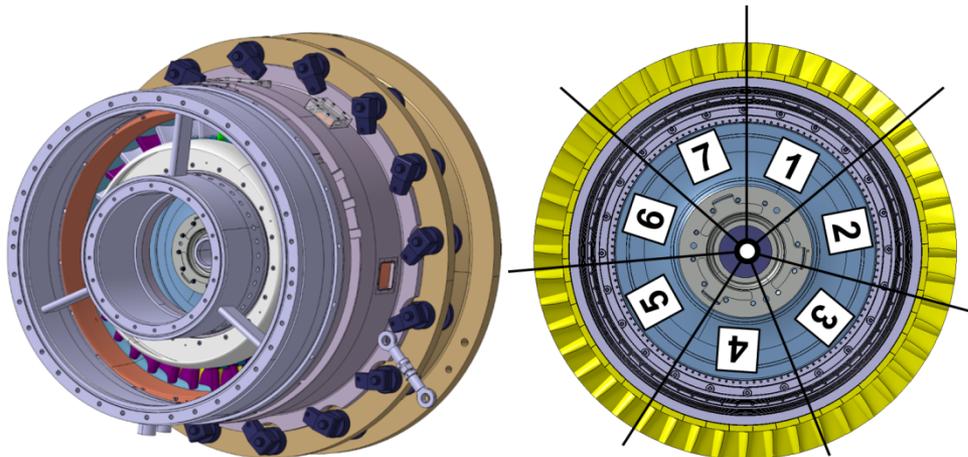
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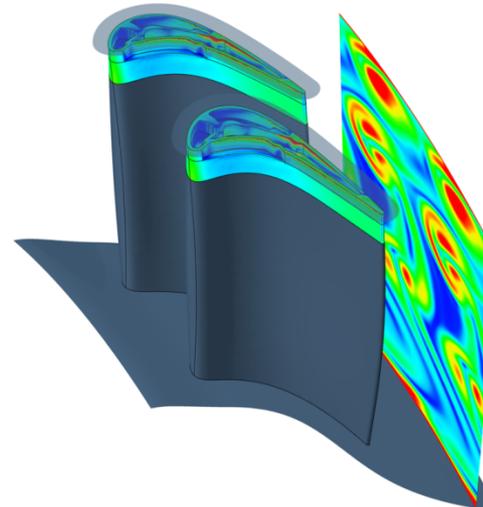
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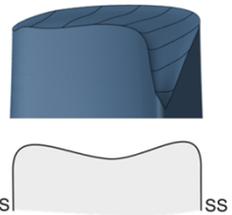
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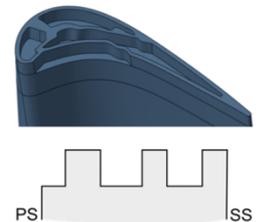
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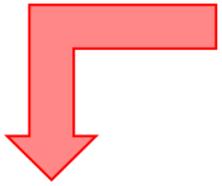
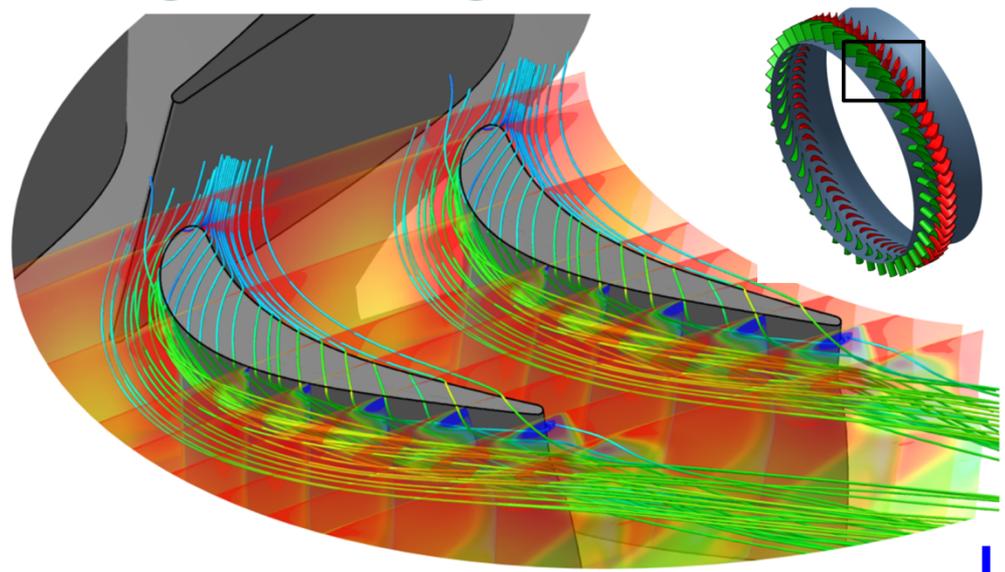
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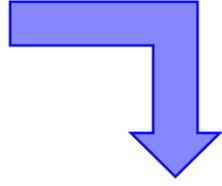
### 2. 'Squealer' designs



# Turbine tip design strategies



Shrouded



Unshrouded



Rolls Royce



Siemens



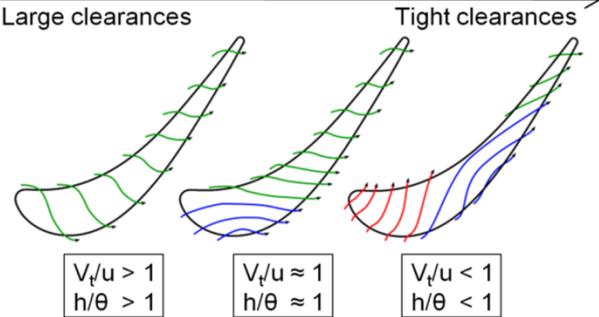
# Turbine tip design strategies

**Shrouded**  
**Unshrouded**

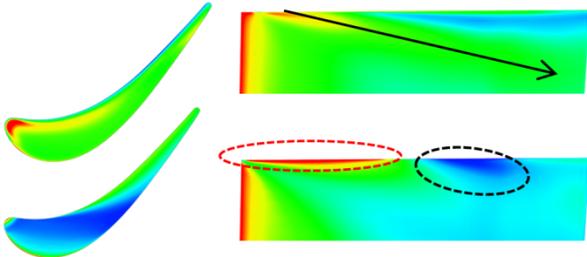


## Tight running tips

### Altered aerodynamics

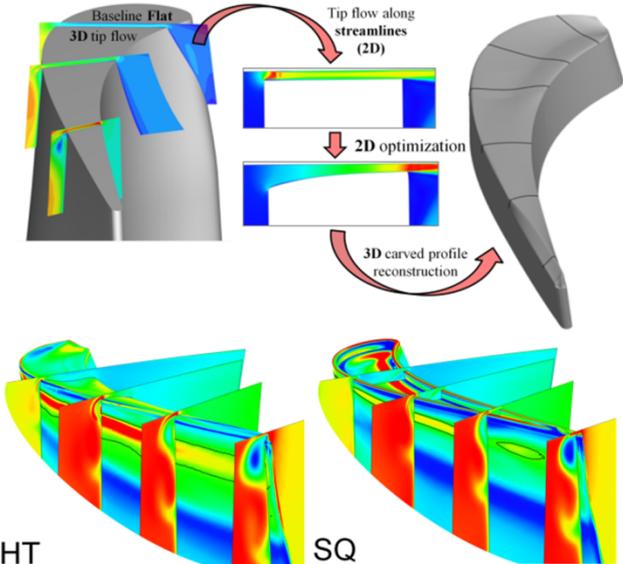


### Altered heat transfer



J. Applied Thermal Engineering, 2014

## Contouring



-18% (flat)  
-39% (SQ)

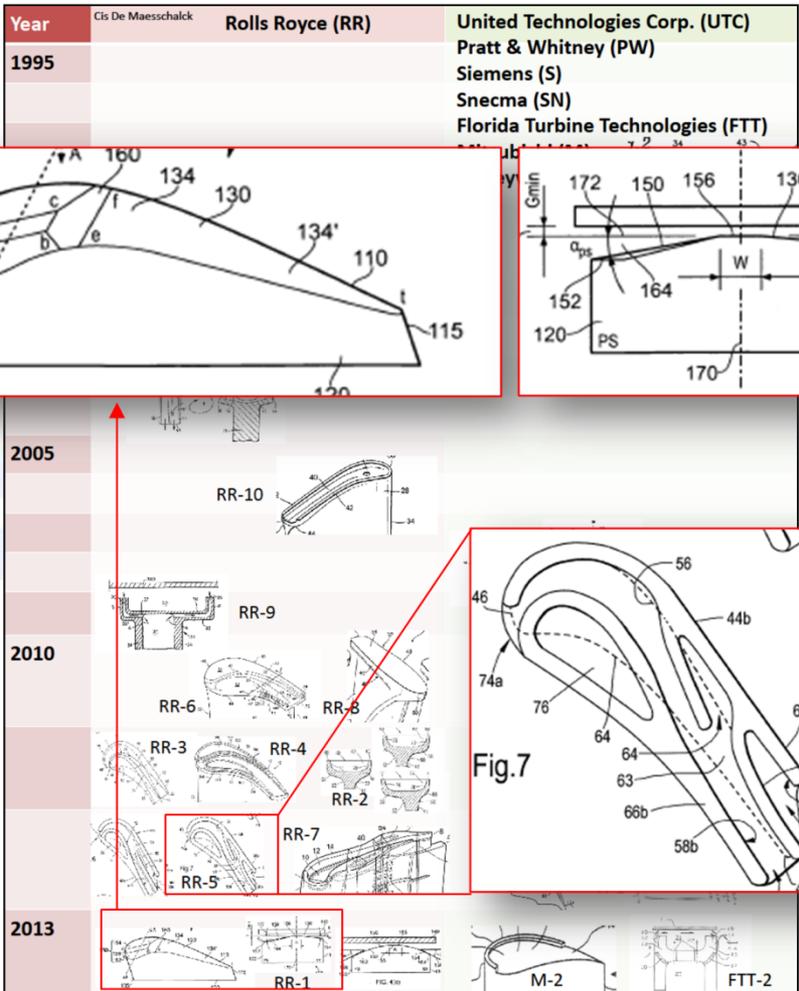
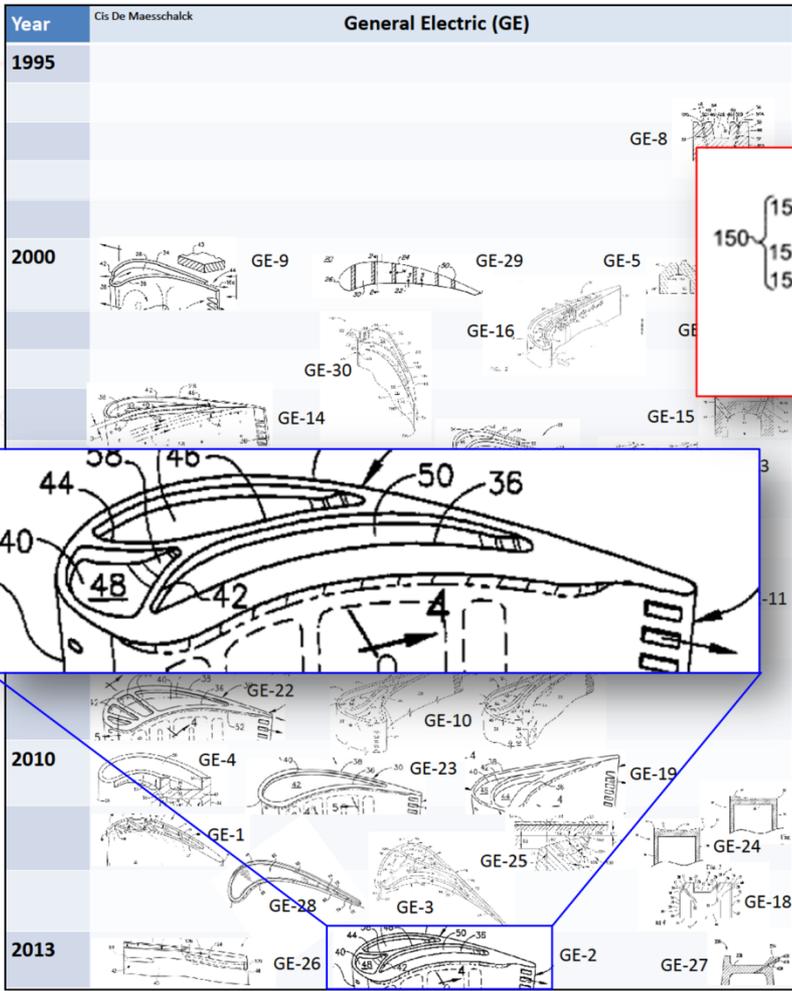
J. Turbomachinery, 2014

## Complex squealer



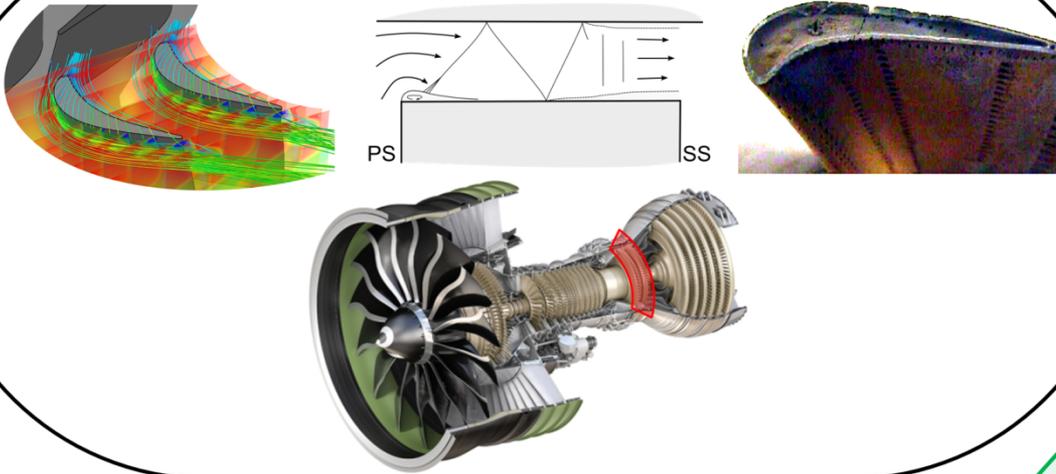
ASME TurboExpo, 2015

# Turbine tip design strategies

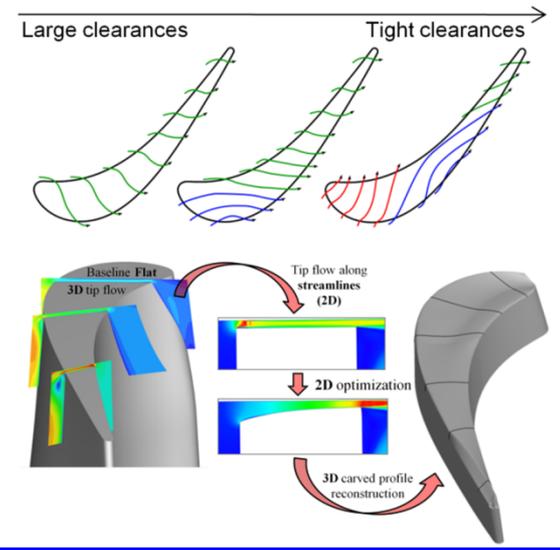


- Over 50 patents were easily found only considering uncooled unshrouded designs
- Reveals the company strategies

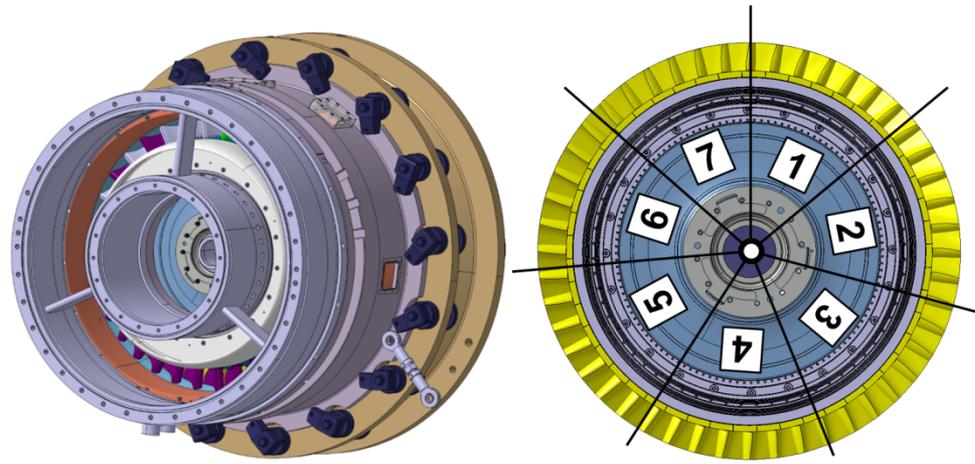
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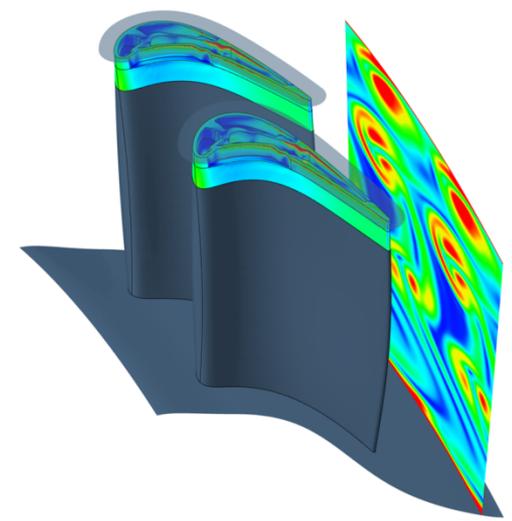
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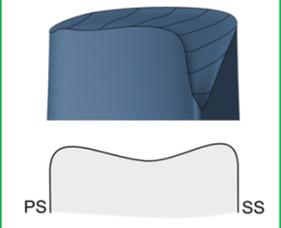
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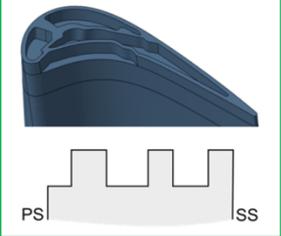
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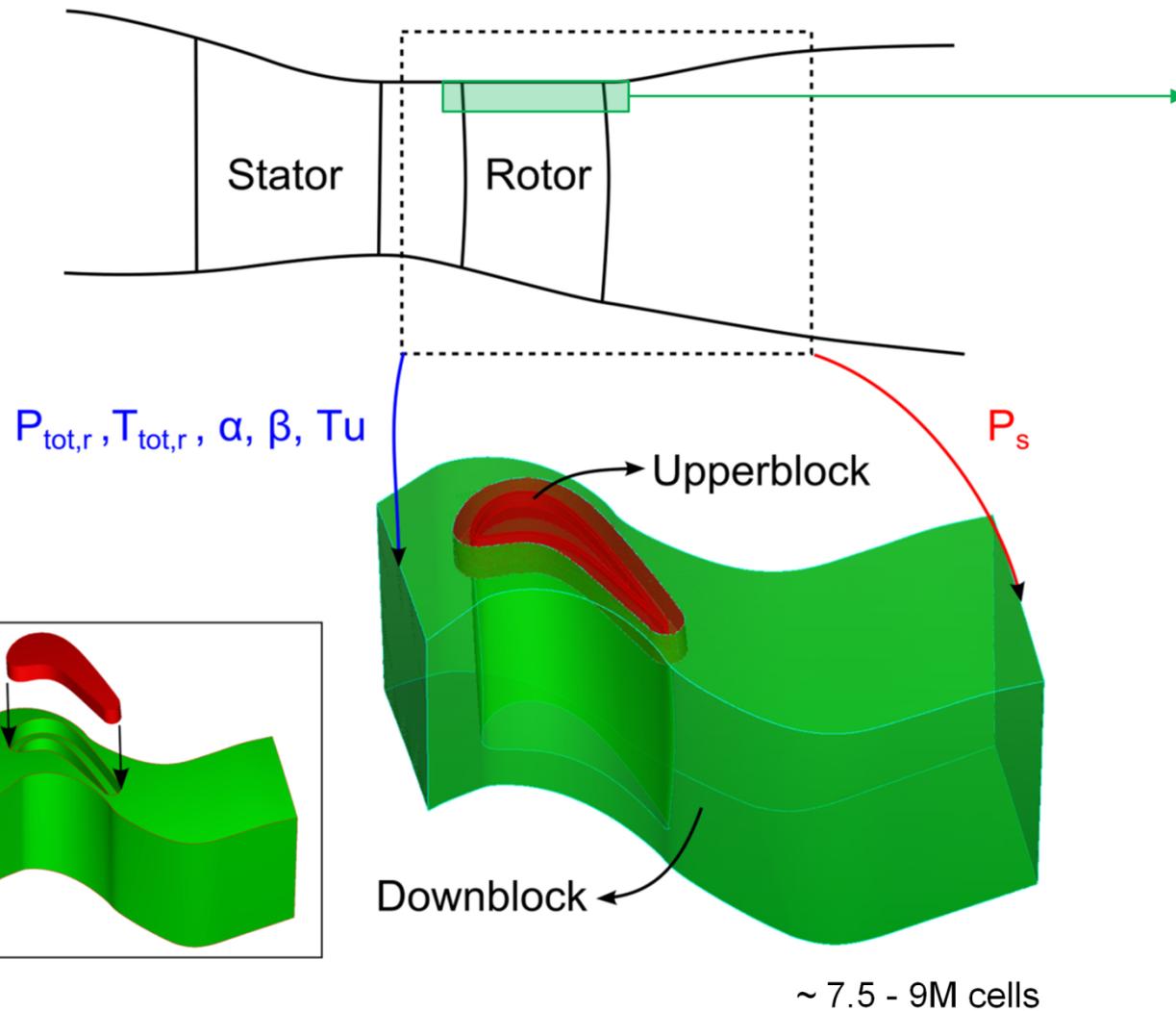
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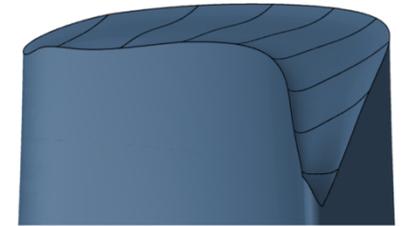
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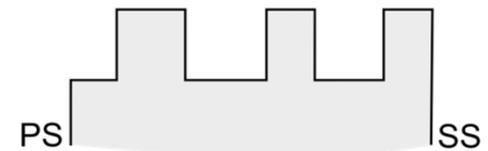
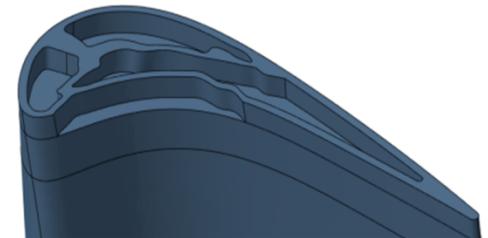
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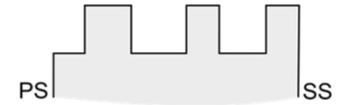
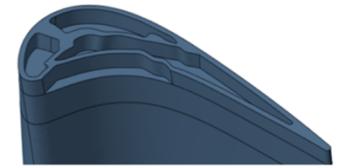
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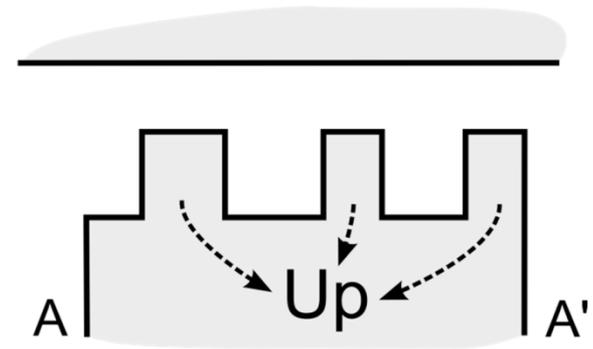
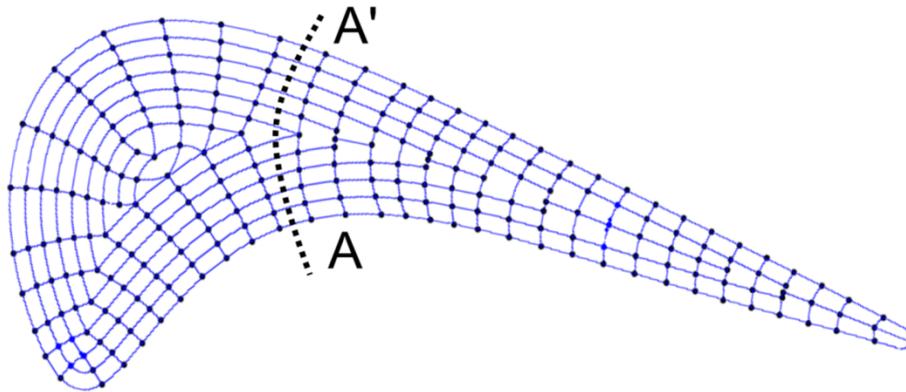
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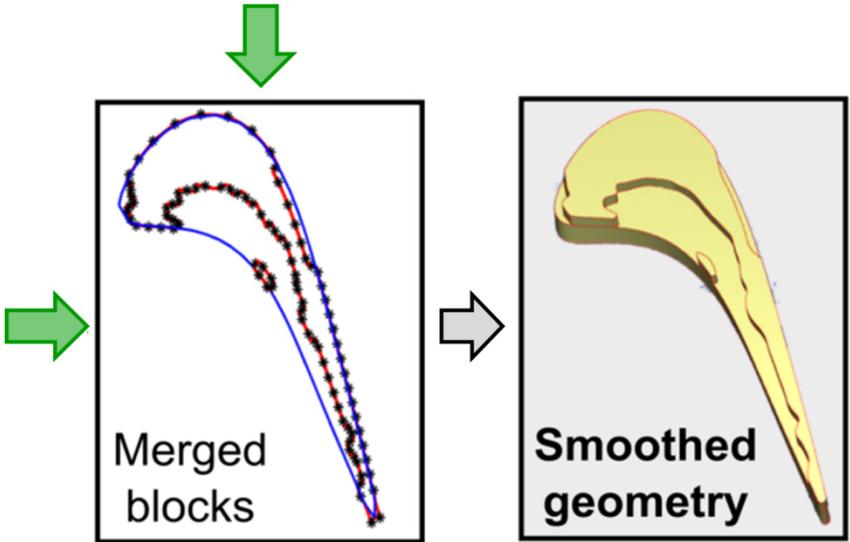
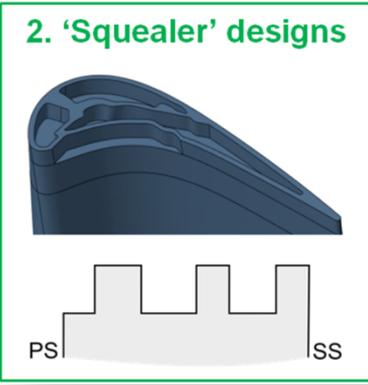
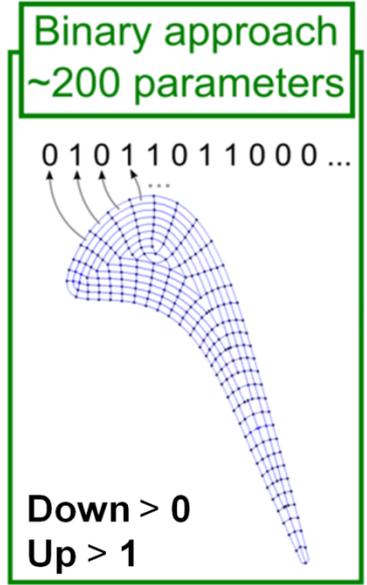
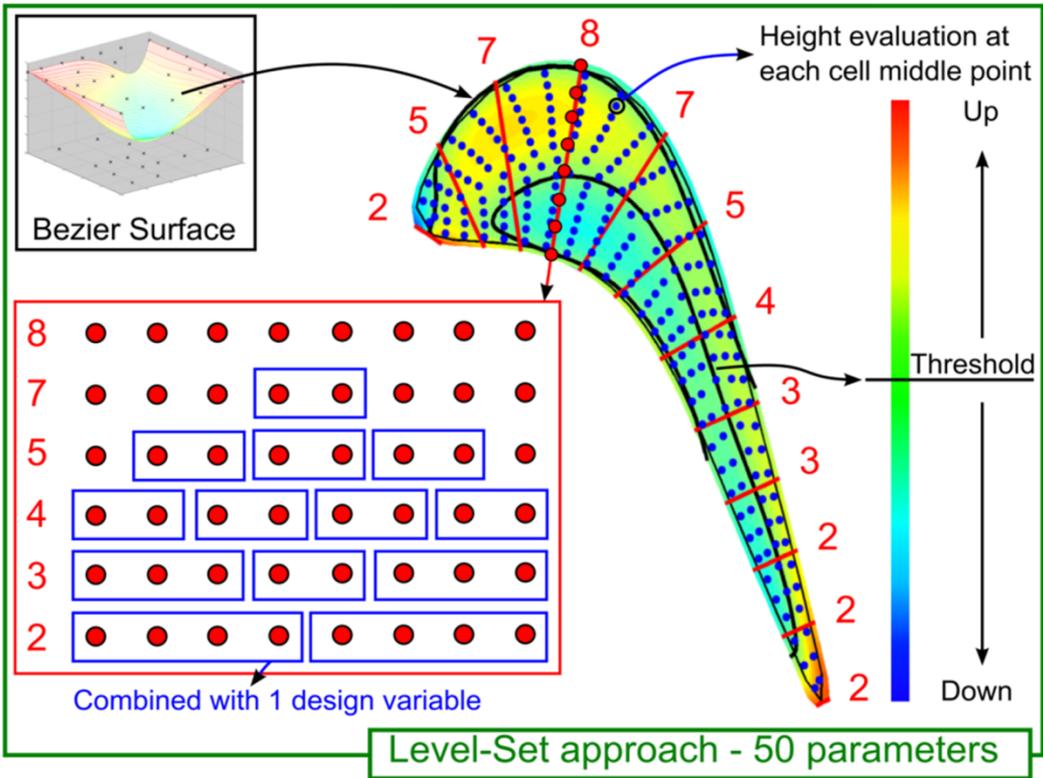




# Squealer Design Optimization

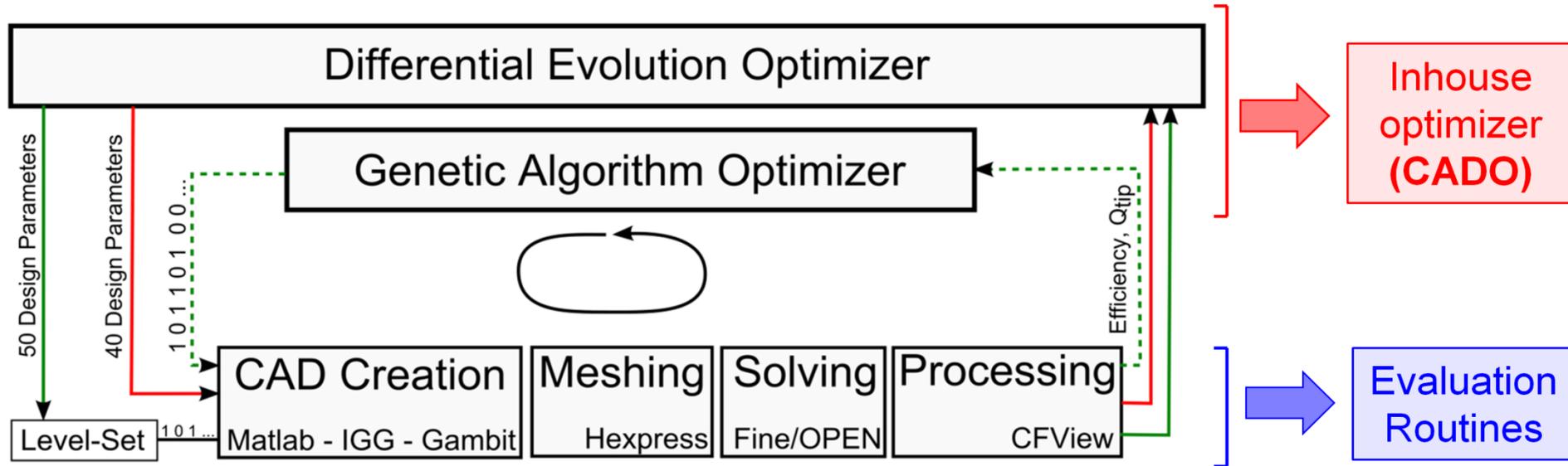


# Squealer Design Optimization



Brevet d'Invention, "Procédé de modélisation d'une baignoire d'une aube", FR, FR1456680, July 10th, 2014

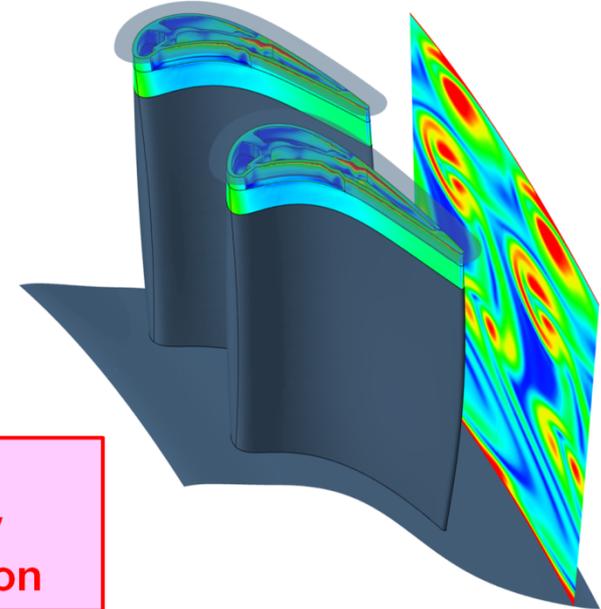
# Numerical Optimization



e.g. Squealer-like



# Numerical Optimization



- For every design a **multitude of performance parameters** was extracted:
  - Heat Transfer, Rotor performance, Downstream non-uniformity, ....
- **4 Multi-objective optimizations** have been conducted (~1500 designs)
- Ran on VKI cluster
  - **320 cores**
  - **+1 month/optimization**

**Objectives:**

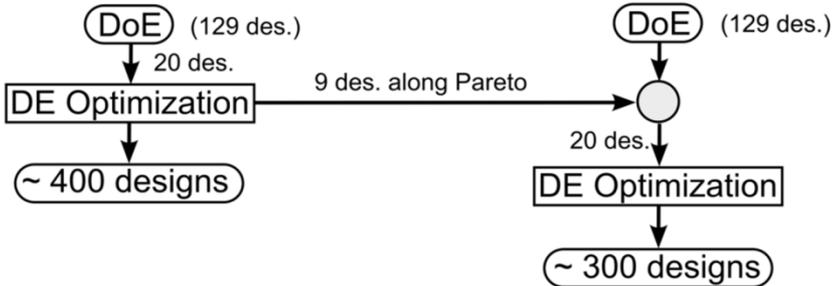
1. Higher **Aerodynamic Efficiency**
2. Reduce **Heat Load onto Tip section**

## Contoured designs

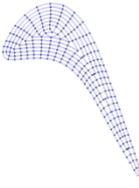
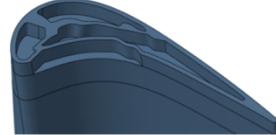
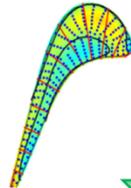


@ Tight clearance

@ Design clearance

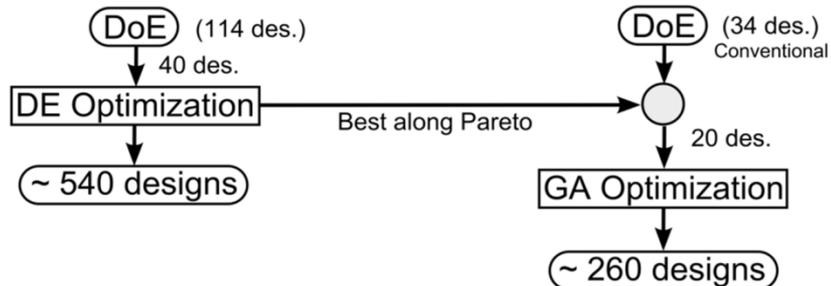


## 'Squealer-like' designs

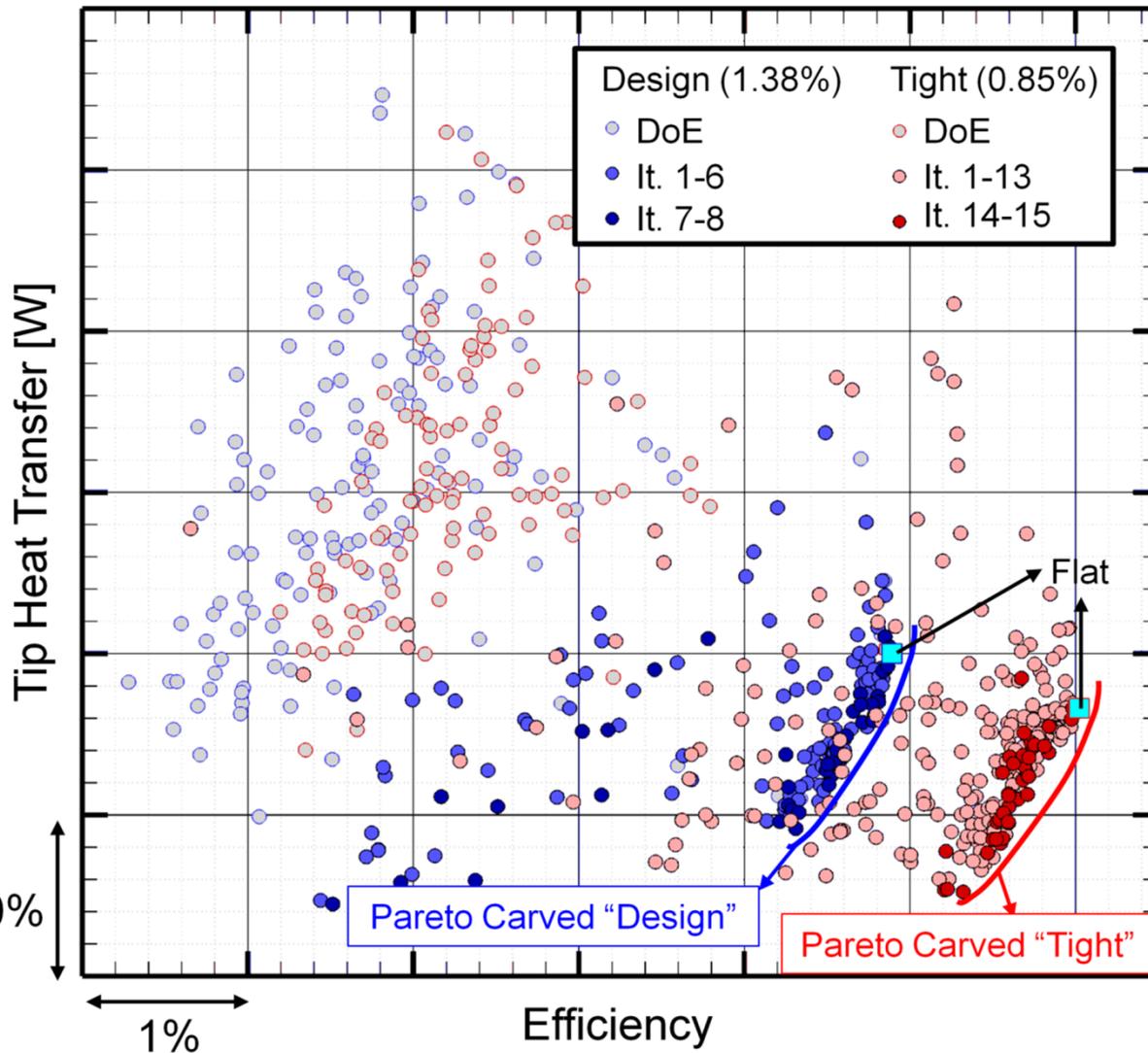


Level Set approach

Binary approach



# Numerical Optimization - Results

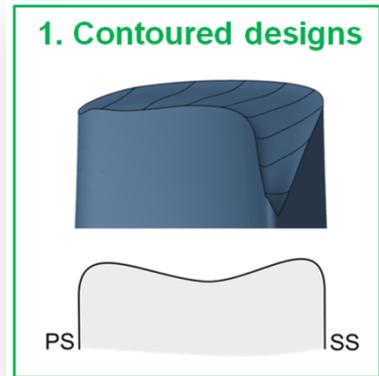


➤ After DoE individuals move fast towards low HT and high efficiencies

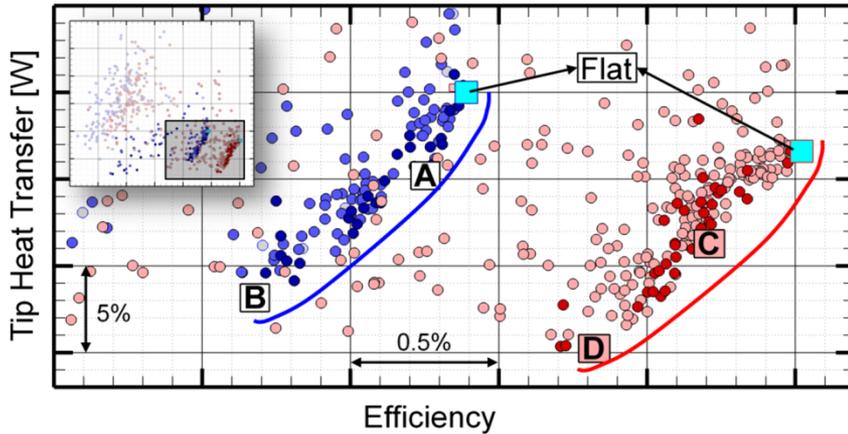
➤ Convergence was accelerated through inclusion of optimal profiles at tight clearance into initial database at design clearance

➤ Reducing gap size by 0.5% increases efficiency by 1%

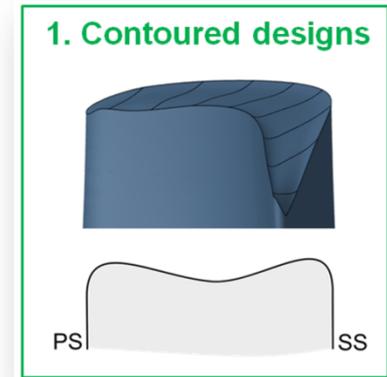
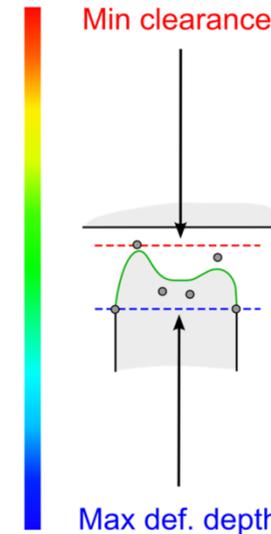
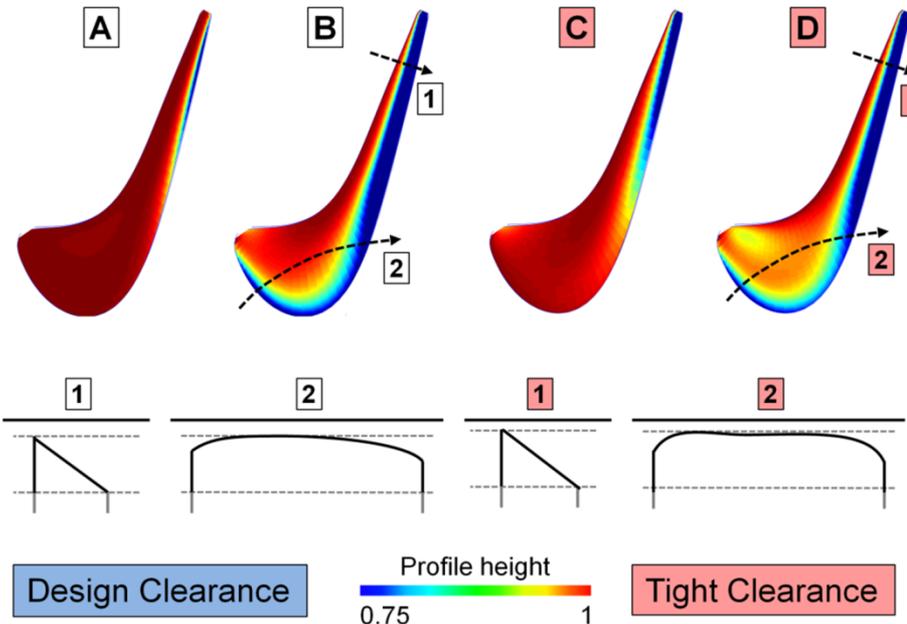
➤ efficiency-HT exchange rate: 1:20



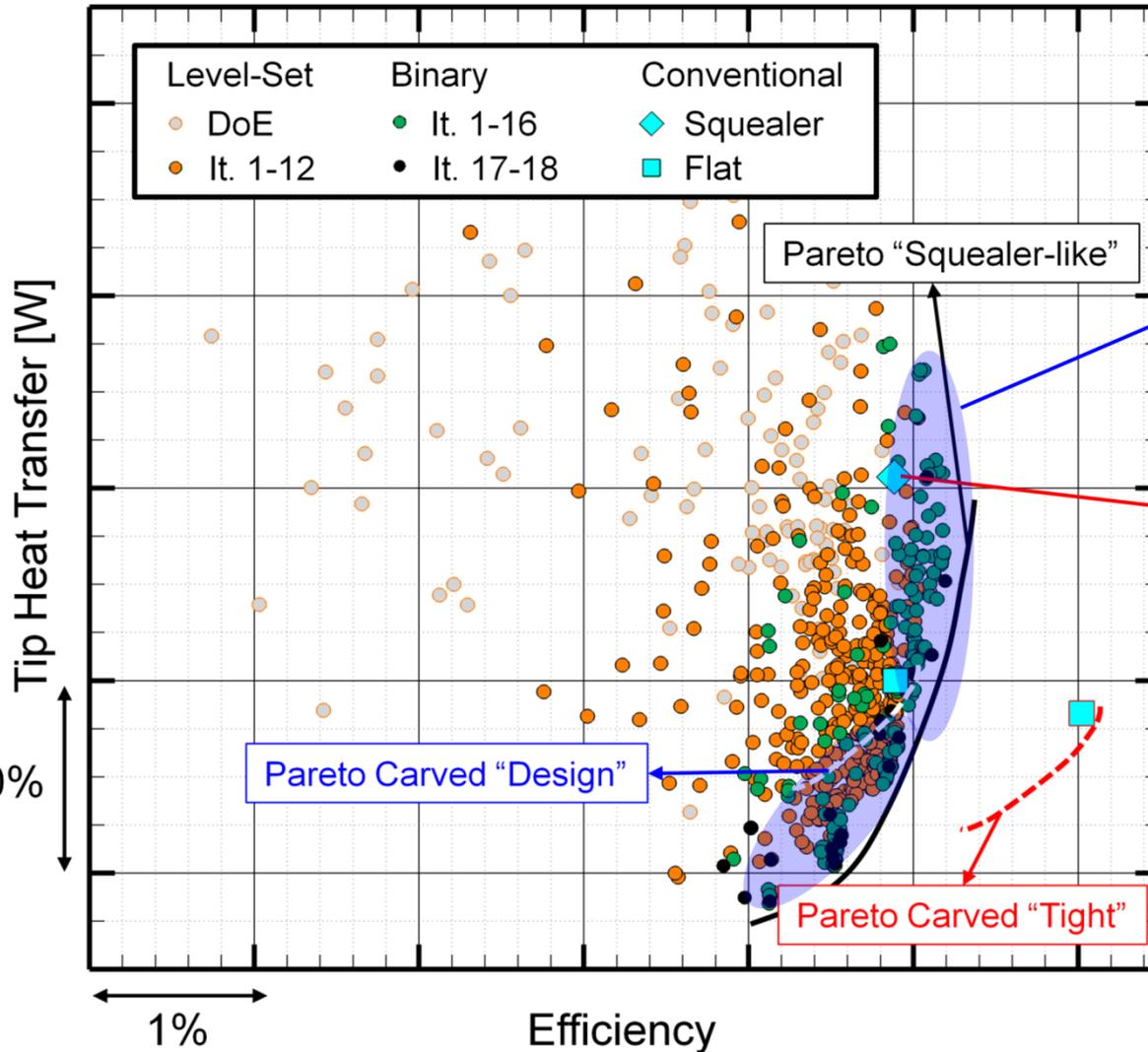
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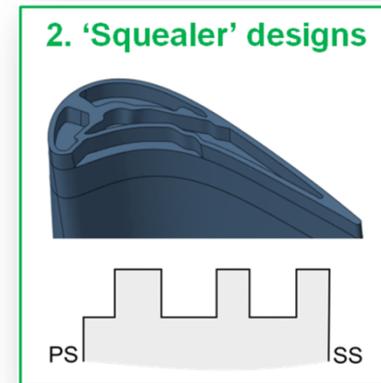
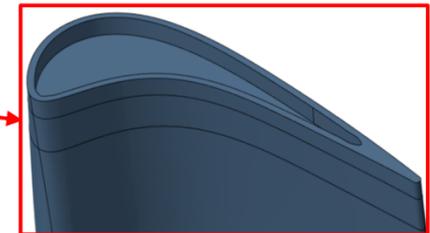
- **Flat tip** prime design for efficiency
- Immediate **HT reduction** of 5% through **opening aft part**
- Further reduction HT (> 10%) possible through **conv. – div. section in front part**
- **Tight running tips** require more **aggressive contouring**



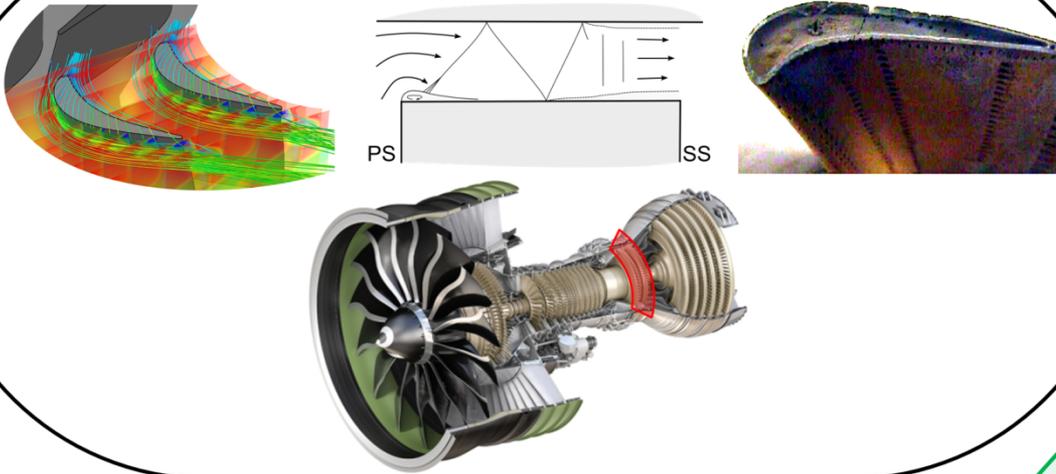
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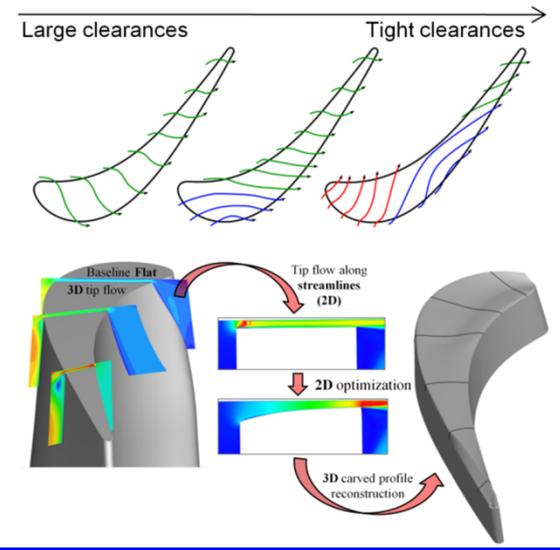
- 2-level optimization
- Squealer-like profiles **twice less sensitive to efficiency**
- Compared to conventional designs:
  - **Efficiency increase of 0.3%**
  - **30% HT reduction**



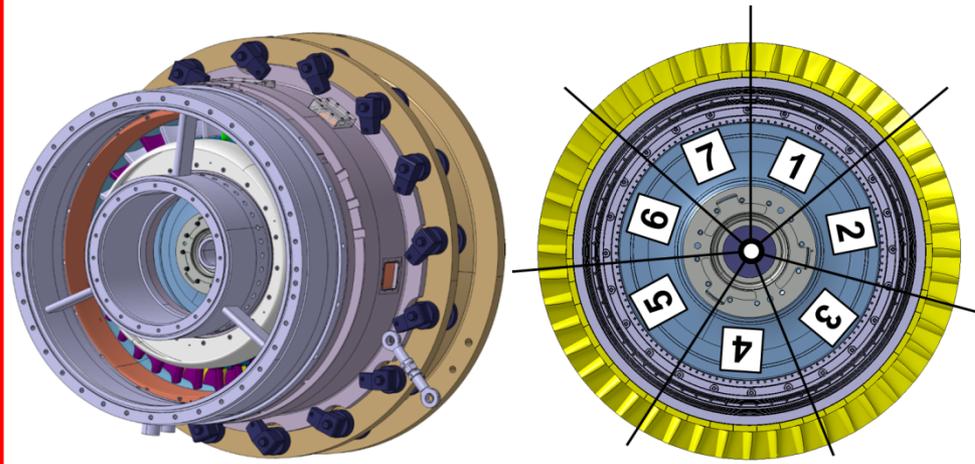
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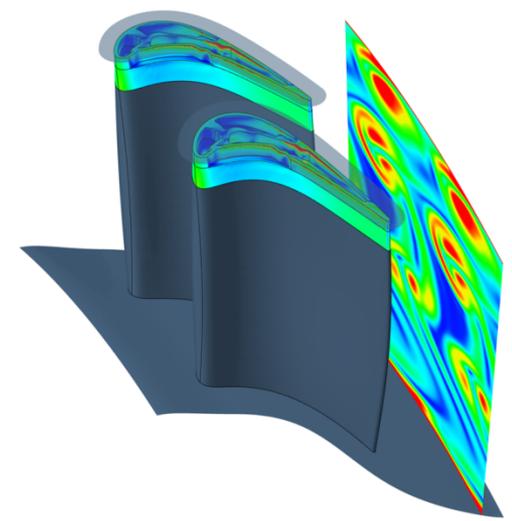
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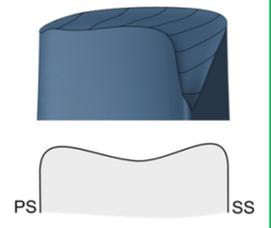
## Experimental Campaign



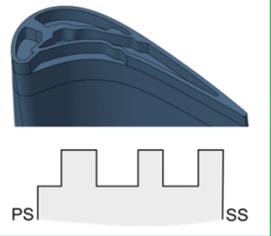
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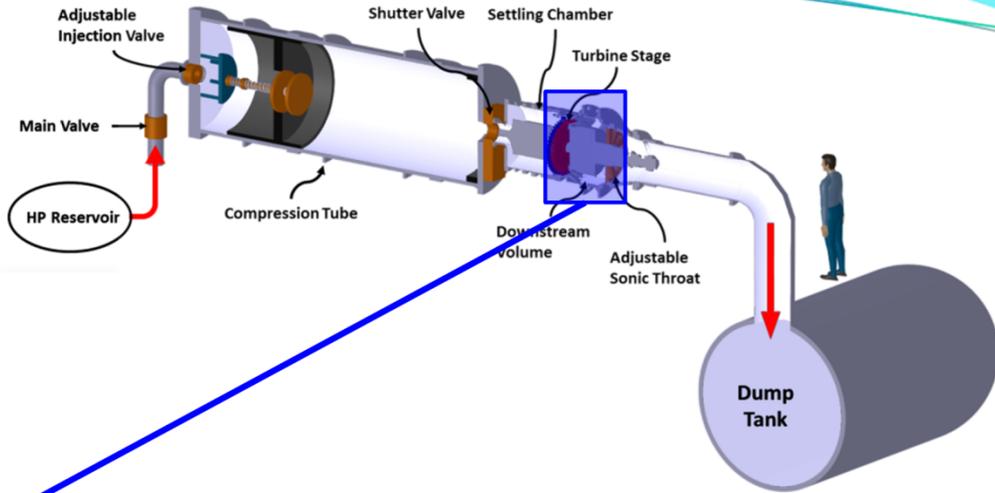
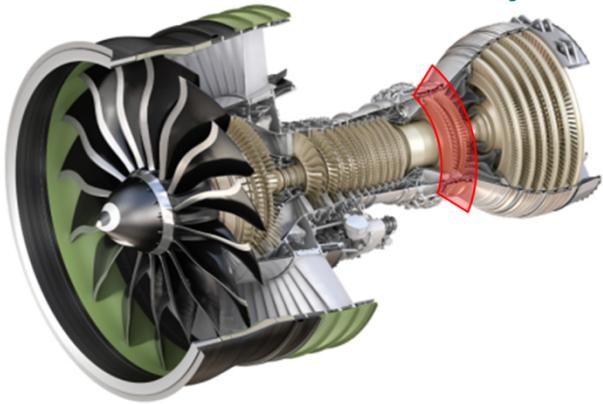
### 1. Contoured designs



### 2. 'Squealer' designs



# Experimental Campaign



Engine



Turbine Rig



Similarity

Reynolds

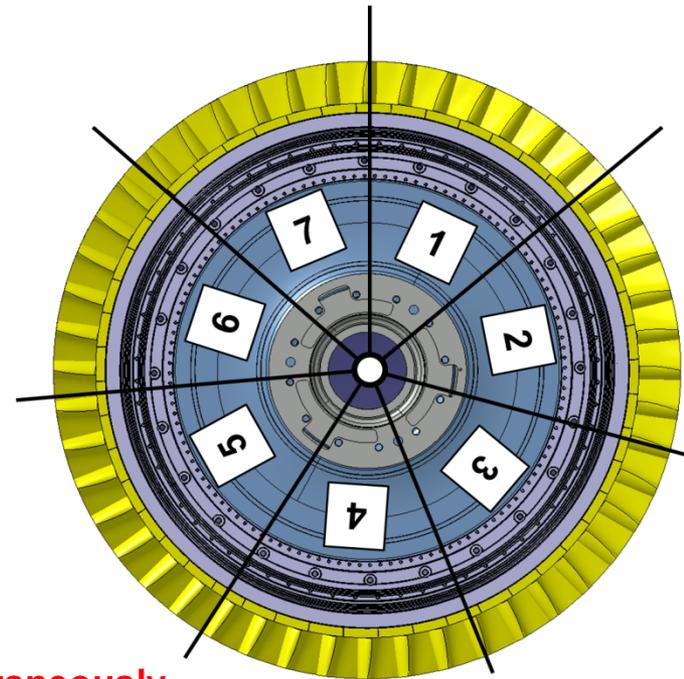
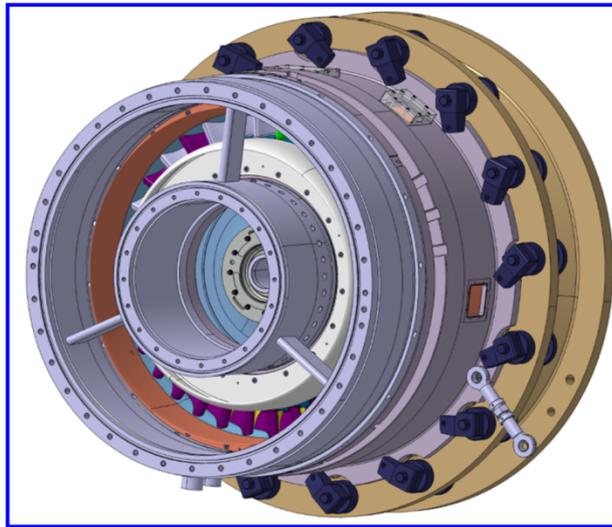
Mach

$T_g/T_w$

$P/P_{01}$ ,  $T/T_{01}$ ,  $\alpha$ ,  $\beta$ , ...

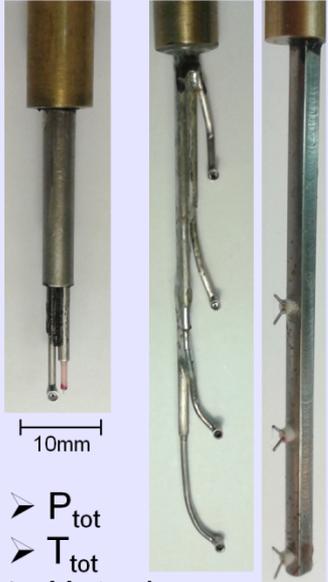
① 1D

② 3D-CFD



➤ Testing of 7 distinct profiles simultaneously

## HPT Inlet



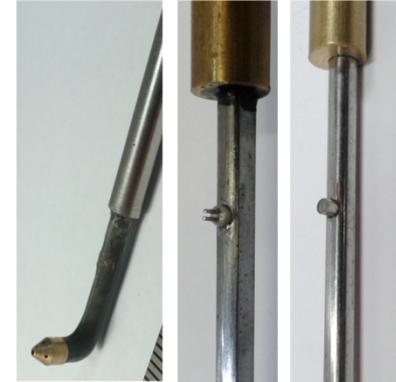
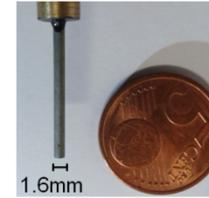
- $P_{tot}$
- $T_{tot}$
- Hot-wires

## Rotor Casing

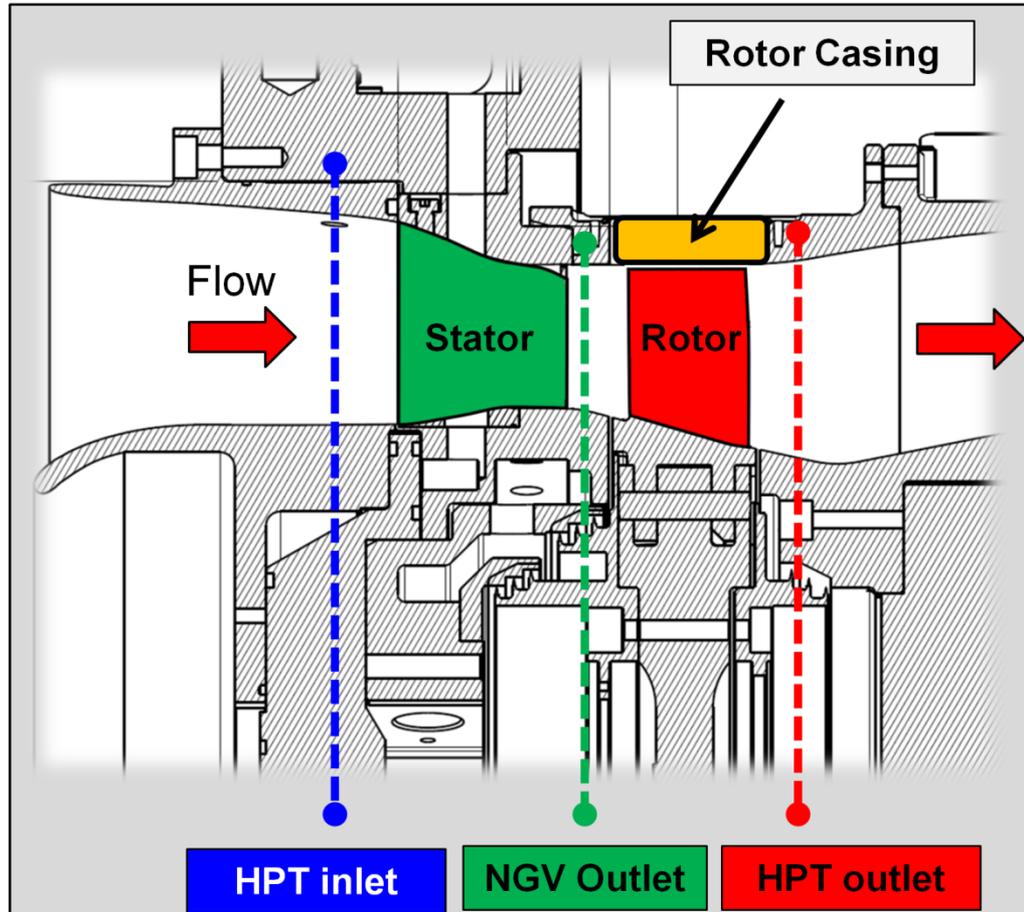


- Tip clearance
- $P_s$  (ST/UNST)
- Heat transfer
- Optical access

## HPT Outlet



- $P_{tot}$
- $T_{tot}$
- $\alpha$
- $\gamma$
- Mach



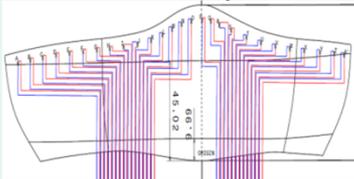
HPT inlet

NGV Outlet

HPT outlet

## NGV

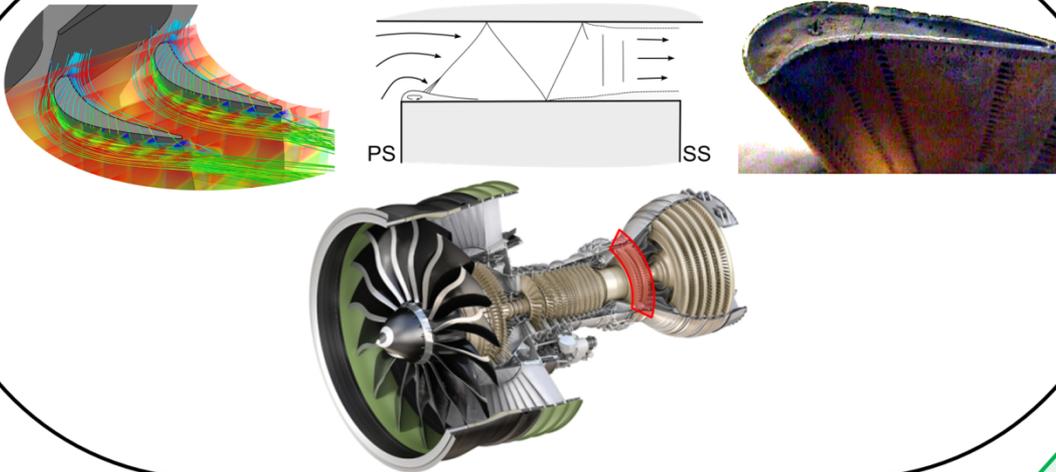
- $P_s$  and HT at 50% and 90% of span



- NGV outlet hub  $P_s$



## TURBINE TIP OPTIMIZATION



### Exploratory Study

- Identified potential for innovation
- Aerothermodynamics at tight clearances
- Optimization of carved profiles using quasi-3D approach

### Experimental Campaign

- Refurbishment of a unique turbine facility allowing simultaneous measurements of 7 distinct profiles
- Development of new miniaturized instrumentation
- Experimental assessment of flow physics for a variety of novel blade tip designs

### Numerical Optimization

- Novel optimization strategy
- 4 consecutive optimizations (~1500 profiles) for contoured and squealer-like profiles
- +0.3% in efficiency  
-30% in Heat transfer

# Turbine Tip Flow Optimization for Modern Aero-Engines

**C. De Maesschalck**

S. Lavagnoli, G. Paniagua, C. Lacor

T. Verstraete

**STP and RM Students:** V. Andreoli, G. Bonetti, A. Bru Revert, D. Cuadrado, G. Latorre, D. Marco Garcia, J. Mcclean, A. Morelli, A. Remiot